

A11100 143735



NAT'L INST. OF STAND & TECH



A11107 209388

# NBS TECHNICAL NOTE 1137

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

## Evaluation of Methods For the Assay of Radium-228 in Water

QC  
100  
.U5753  
No. 1137  
1981  
c.2

## NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards<sup>1</sup> was established by an act of Congress on March 3, 1901. The Bureau's overall goal is to strengthen and advance the Nation's science and technology and facilitate their effective application for public benefit. To this end, the Bureau conducts research and provides: (1) a basis for the Nation's physical measurement system, (2) scientific and technological services for industry and government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety. The Bureau's technical work is performed by the National Measurement Laboratory, the National Engineering Laboratory, and the Institute for Computer Sciences and Technology.

**THE NATIONAL MEASUREMENT LABORATORY** provides the national system of physical and chemical and materials measurement; coordinates the system with measurement systems of other nations and furnishes essential services leading to accurate and uniform physical and chemical measurement throughout the Nation's scientific community, industry, and commerce; conducts materials research leading to improved methods of measurement, standards, and data on the properties of materials needed by industry, commerce, educational institutions, and Government; provides advisory and research services to other Government agencies; develops, produces, and distributes Standard Reference Materials; and provides calibration services. The Laboratory consists of the following centers:

Absolute Physical Quantities<sup>2</sup> — Radiation Research — Thermodynamics and Molecular Science — Analytical Chemistry — Materials Science.

**THE NATIONAL ENGINEERING LABORATORY** provides technology and technical services to the public and private sectors to address national needs and to solve national problems; conducts research in engineering and applied science in support of these efforts; builds and maintains competence in the necessary disciplines required to carry out this research and technical service; develops engineering data and measurement capabilities; provides engineering measurement traceability services; develops test methods and proposes engineering standards and code changes; develops and proposes new engineering practices; and develops and improves mechanisms to transfer results of its research to the ultimate user. The Laboratory consists of the following centers:

Applied Mathematics — Electronics and Electrical Engineering<sup>2</sup> — Mechanical Engineering and Process Technology<sup>2</sup> — Building Technology — Fire Research — Consumer Product Technology — Field Methods.

**THE INSTITUTE FOR COMPUTER SCIENCES AND TECHNOLOGY** conducts research and provides scientific and technical services to aid Federal agencies in the selection, acquisition, application, and use of computer technology to improve effectiveness and economy in Government operations in accordance with Public Law 89-306 (40 U.S.C. 759), relevant Executive Orders, and other directives; carries out this mission by managing the Federal Information Processing Standards Program, developing Federal ADP standards guidelines, and managing Federal participation in ADP voluntary standardization activities; provides scientific and technological advisory services and assistance to Federal agencies; and provides the technical foundation for computer-related policies of the Federal Government. The Institute consists of the following centers:

Programming Science and Technology — Computer Systems Engineering.

<sup>1</sup>Headquarters and Laboratories at Gaithersburg, MD, unless otherwise noted; mailing address Washington, DC 20234.

<sup>2</sup>Some divisions within the center are located at Boulder, CO 80303.

# Evaluation of Methods For the Assay of Radium-228 in Water

J. R. Noyce

Center for Radiation Research  
National Measurement Laboratory  
National Bureau of Standards  
Washington, DC 20234

Sponsored by:  
Quality Assurance Division  
Environmental Monitoring Systems Laboratory  
U.S. Environmental Protection Agency, P.O. Box 15027  
Las Vegas, NV 89114



U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, Secretary  
U.S. NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

Issued February 1981

**National Bureau of Standards Technical Note 1137**

Nat. Bur. Stand. (U.S.), Tech. Note 1137, 18 pages (Feb. 1981)

CODEN: NBTNAL

U.S. GOVERNMENT PRINTING OFFICE  
WASHINGTON: 1980

---

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

Price \$1.50

(Add 25 percent for other than U.S. mailing)

# EVALUATION OF METHODS FOR THE ASSAY OF RADIUM-228 IN WATER

by

J. R. Noyce

The technical literature from 1967 to May 1980 was searched for methods for assaying radium-228 in water. These methods were evaluated for their suitability as potential EPA reference methods for drinking water assays. We suggest the present EPA reference method (Krieger, 1976) be retained but improved, and a second method (McCurdy and Mellor, 1979), which employs  $\beta$ - $\gamma$  coincidence counting, be added. Included in this report is a table that lists the principal features of 17 methods for radium-228 assays.

Key words: Analysis; assay; evaluation; radioactivity; radiochemistry; radium-228; reference method; water.

## Introduction

Radium-228 is a radionuclide hazardous to human health because, like radium-226, it is incorporated into the skeleton and has a long biological residence time. Radium-228 is ingested primarily by the drinking of water. It has been found to occur in higher concentrations than  $^{226}\text{Ra}$  in water in contact with some geologic formations in the United States (Johnson, 1971; Michel and Moore, 1980) and in Brazil (Hainberger, 1974). Radium-228 is difficult to assay accurately, especially at low concentrations, because it emits only very low-energy conversion electrons (less than 6 keV) and low-energy beta particles (10 keV average energy). Other isotopes of radium or their daughters cannot readily be added to samples as tracers for measuring the chemical yields of assays because: 1) they are also likely to be present in the water, particularly  $^{224}\text{Ra}$  and  $^{226}\text{Ra}$ , or 2) they are themselves inconvenient to prepare and assay, as in the cases of  $^{223}\text{Ra}$  and  $^{225}\text{Ra}$ .



The U. S. Environmental Protection Agency has regulations which set limits on the concentrations of radionuclides, including  $^{228}\text{Ra}$ , in drinking water (EPA, 1976), and which specify approved assay methods. The EPA reference method for  $^{228}\text{Ra}$  (Krieger, 1976) is based on a U.S. Geological Survey method (Johnson, 1971), which was also recommended by the World Health Organization (Lund, 1976). In addition, the U.S. Food and Drug Administration (FDA, 1979) has regulations pertaining to radionuclides in bottled water, modelled on the EPA regulations. Other methods for the low-level assay of  $^{228}\text{Ra}$  are available, but each of them, as well as the present reference method, has one or more deficiencies for use in monitoring.

All assay methods for radionuclides should have sufficient and demonstrated precision, accuracy, and sensitivity to meet the purposes of the assay. With the possible exception of simple screening tests, such as "gross  $\alpha$ " measurements, all radiochemical methods also should incorporate steps for determining the chemical yield.

There are additional desirable features that should be present in an ideal monitoring method. The method should be "rugged", which means it will perform well under less than ideal conditions. It should provide results without requiring a long wait for the ingrowth or decay of a radionuclide, and it should be suitable for use with large numbers of samples; that is, it should have relatively low labor and supply costs.

The Quality Assurance Division in the Environmental Monitoring Systems Laboratory of the EPA, Las Vegas, requested the NBS Radioactivity Group, Nuclear Radiation Division, to survey the literature for  $^{228}\text{Ra}$  assay methods and evaluate their suitability as potential EPA reference methods.

## Survey of Literature

Nuclear Science Abstracts was searched from 1967 until its termination in 1977. Then, the Energy Data Base was searched from 1977 through May 1980. Also, Chemical Abstracts was searched from 1968 through May 1980. References cited in the relevant papers found in these searches led to other papers dating from approximately 1960.

There are only a few papers giving methods for assaying  $^{228}\text{Ra}$  in water and the results of such measurements. Many of the available papers deal with seawater rather than fresh water. The pertinent aspects of the methods are set forth in Table 1 in alphabetical order of author. Some of these publications also deal with  $^{226}\text{Ra}$  assays, and salient features of these methods are included in Table 1. Papers concerned only with  $^{226}\text{Ra}$  assays are not included.

Also in Table 1 are  $^{228}\text{Ra}$  assay procedures found during the search that are for other types of samples, such as soil. The latter methods usually can be adapted to the assay of water samples, and some contain useful techniques not exploited in the water-assay procedures. Reports of investigations using previously published  $^{228}\text{Ra}$  assay procedures are excluded.

## Evaluation of Methods

Most of the following discussion further explains important points made in Table 1. Nearly all the assay methods separate and purify  $^{228}\text{Ac}$  and count beta particles emitted in its decay. The method of McCurdy and Mellor (1979) is unique in that the  $^{228}\text{Ac}$  is not separated from its  $^{228}\text{Ra}$  parent for counting. Thus,  $^{228}\text{Ac}$  can be counted as long as desired or recounted days later

without performing additional radiochemistry on the sample. A few procedures use the detection of radiations emitted by later members in the  $^{228}\text{Ac}$  decay series, including  $^{228}\text{Th}$ ,  $^{224}\text{Ra}$ , and even  $^{212}\text{Pb}$  from de-emanated  $^{220}\text{Rn}$ . Only the method of Tomza (1977) uses liquid-scintillation counting.

The assay methods listed in Table 1 appear to have the sensitivity required by the EPA drinking water regulations (EPA, 1976), with the apparent exceptions of those of Iyer et al. (1966) and Baretta and Feldman (1961). There is some evidence that at low  $^{228}\text{Ra}$  concentrations a method for counting alpha particles from the decay of  $^{228}\text{Th}$  has better precision than one for counting beta particles from the decay of  $^{228}\text{Ac}$  (Knauss et al., 1978), but the time required for  $^{228}\text{Th}$  ingrowth is much longer than that for  $^{228}\text{Ac}$ .

The methods in Table 1 lacking a provision for determining the chemical yield for each sample processed are those of Humphrey et al. (1975), Johns et al. (1979), Kuchta et al. (1976), MacKenzie et al. (1979), Percival and Martin (1974), Petrow et al. (1964), Sakanoue et al. (1973), and Tomza (1977). This is also true of procedures of Barratta and Feldman (1961), and of Kahlos and Asikainen (1973), but both could readily be modified for gravimetric determination of chemical yields. Some of the methods which do provide a chemical yield, however, require long waiting times (see below).

Four of the methods use radioactive tracers to measure chemical yields: Kaufman et al. (1973), Koide and Bruland (1975), Michel and Moore (1980), and Smith and Mercer (1970). Because the present EPA reference methods for radionuclides other than tritium do not require radioactive tracers (Krieger, 1976), it was assumed they are to be avoided when another yield-measuring technique



is available. It should be noted that the chemical yield is incorrectly calculated in the reference method for  $^{228}\text{Ra}$  (Krieger, 1976). Any loss of sample in steps 13 and 14 is counted twice. The  $\text{Ba}(\text{Ra})\text{SO}_4$  precipitate at the end of step 11 should be weighed, rather than in step 25 as stated.

The waiting periods in the methods given in Table 1 for ingrowth or decay of radionuclides during an assay can be divided into three groups: less than two full days, two days to 30 days, and greater than 30 days. Waiting periods include time for the ingrowth of  $^{222}\text{Rn}$  for those procedures where assays of  $^{226}\text{Ra}$  are an integral part of the  $^{228}\text{Ra}$  assays. The short-time procedures in the first group are Baratta and Feldman (1961), Humphrey et al. (1975), Iyer et al. (1966), Krieger (1976), McCurdy and Mellor (1979), Percival and Martin (1974), and Petrow et al. (1964). Methods with waiting periods of between two and 30 days are Johns et al. (1979), Kahlos and Asikainen (1973), Koide and Bruland (1975), and Smith and Mercer (1970) (via  $^{228}\text{Ac}$ ). Methods requiring waiting times of longer than 30 days are Kaufman et al. (1973), Kuchta et al. (1976), MacKenzie et al. (1979), Michel and Moore (1980), Sakanoue et al. (1973), Smith and Mercer (1970) (via  $^{228}\text{Th}$ ), and Tomza (1977).

The methods of Kuchta et al. (1976) and Tomza (1977) would have waiting times of only two to 30 days if  $^{224}\text{Ra}$  were known to be in equilibrium with  $^{228}\text{Ra}$ , but this condition would probably be rare for drinking water. Finally, the waiting period in the procedure of MacKenzie et al. (1979) could also be reduced to between two and 30 days if the more volatile beta-particle-emitting progeny of  $^{228}\text{Ac}$  could be flamed off a

source evaporated on a stainless steel planchet with no accompanying loss of  $^{228}\text{Ac}$  (compare with Koide and Bruland (1975)).

A potential problem confronting the methods which assay  $^{228}\text{Ra}$  via  $^{228}\text{Ac}$  is the presence of radioisotopes of the rare-earth elements or those with similar chemical properties, especially  $^{90}\text{Y}$ , daughter of  $^{90}\text{Sr}$ . Some of the procedures have one or more steps designed to reduce such contamination, and the  $\beta$ - $\gamma$  coincidence counting technique of McCurdy and Mellor (1979) is not affected by  $^{90}\text{Y}$ . A recent interlaboratory assay exercise, with a water test sample that had  $^{90}\text{Sr}$ - $^{90}\text{Y}$  added, indicated that the present EPA reference method does not adequately remove  $^{90}\text{Y}$  from  $^{228}\text{Ac}$  (Whittaker, 1980).

The Y or La compound chosen as the carrier for Ac should be checked for radiochemical purity before use, because it may be a significant source of beta activity (Johnson, 1971). Such a warning should be added to the reference method.

It is difficult to assess the "ruggedness" of an analytical method from just a literature survey. In general, the less complex an assay procedure is, the better chance of its being "rugged". However, some of the simpler procedures in Table 1 are without a means for measuring chemical yields.

The "special apparatus" columns in the table list items needed for each method that are judged not likely to be present in the usual water-analysis laboratory. Some of these items, such as the  $\beta$ - $\gamma$  coincidence-counting system of McCurdy and Mellor (1979), are a significant expense.

## Conclusions

Most of the  $^{228}\text{Ra}$  assay methods in Table 1 are eliminated from consideration as an EPA reference method by applying the criteria discussed earlier: adequate sensitivity, yield determination without radioactive tracers, and a waiting time for ingrowth or decay of radionuclides in the sample of no more than 30 days. The methods meeting these criteria, but with the reservation already noted about each, are Kahlos and Asikainen (1973), Krieger (1976) and McCurdy and Mellor (1979). The first of these three would be eliminated if the requirement of a waiting period for ingrowth or decay of no more than two days were imposed. It is possible that Iyer et al. (1966) and Barratta and Feldman (1961) are sufficiently sensitive, but multilaboratory studies would be necessary to demonstrate this.

It is suggested that the EPA keep Krieger (1976) as a reference method but improve its decontamination factor for  $^{90}\text{Y}$  and correct its chemical yield calculation. It is also suggested that McCurdy and Mellor (1979) be added as a second reference method. The two procedures complement each other. The first uses radiation-detection systems which most laboratories that assay for radionuclides in water are likely to have, but it requires a considerable amount of labor to process samples. The second requires most laboratories to purchase a new radiation-detection system, but the labor to process samples is definitely less.

## Literature

Baratta, E.J., and M.H. Feldman (1961), Determination of Actinium in Uranium Mill Effluents, U.S.A.E.C. Topical Report WIN-123.

Broecker, W.S., A. Kaufman, and R.M. Trier (1973), "The residence time of thorium in surface sea water and its implications regarding the rate of reactive pollutants", *Earth Planet. Sci. Lett.*, 20, 35.

Cochran, J.K. (1979), The Geochemistry of  $^{226}\text{Ra}$  and  $^{228}\text{Ra}$  in Marine Deposits, Ph. D. thesis, Yale Univ., App. A.

EPA (1976), National Interim Primary Drinking Water Regulations, EPA-570/9-76-003, U.S.E.P.A., Washington.

FDA (1979), "Quality standards for foods with no identity standards - bottled water", *Fed. Reg.*, 44 (45), 12169.

Goldin, A.S. (1961), "Determination of dissolved radium", *Anal. Chem.*, 33, 406.

Hainberger, P.L., I.R. de Oliveira Paiva, H.A. Salles Andrade, G. Zundel, and T.L. Cullen (1974), "Radioactivity in Brazillian mineral waters", *Radiat. Data Rep.*, 15 (8), 483.

Humphrey, H.W., E.L. Adkins, and G.G. Templin (1975), The Radiometric Determination of  $^{226}\text{Ra}$  and  $^{228}\text{Ra}$  in Waste Effluent Solutions, U.S.A.E.C. Report NLC0-1084.

Iyer, R.H., H.C. Jain, M.V. Ramaniah, and C.L. Rao (1966), "Estimation of radium-228 in monazite and thorium samples", *Radiochim. Acta*, 5, 56.

Johns, F.B., P.B. Hahn, D.J. Thome, and E.W. Bretthauer (1979), Radiochemical Analytical Procedures for Analysis of Environmental Samples, U.S.E.P.A. Report EMSL-LV-0539-17, Las Vegas.

Johnson, J.O. (1971), Determination of Radium-228 in Natural Waters, U.S.G.S. Water-Supply Paper 1696-G, Washington.

Kahlos, H., and M. Asikainen (1973), Natural Radioactivity of Ground Water in the Helsinki Area, Institute of Radiation Physics Report SFL-A-19, Helsinki.

Kaufman, A., R.M. Trier, W.S. Broecker, and H.W. Feely (1973), "Distribution of  $^{228}\text{Ra}$  in the world ocean", *J. Geophys. Res.*, 78 (36), 8827.

Knauss, K.G., T.-L. Ku, and W.S. Moore (1978), "Radium and thorium isotopes in the surface waters of the east Pacific and coastal southern California", *Earth Planet. Sci. Lett.*, 39, 235.



Koide, M., and K.W. Bruland (1975), "The electrodeposition and determination of radium by isotopic dilution in sea water and in sediments simultaneously with other natural radionuclides", *Anal. Chim. Acta*, 75, 1.

Krieger, H.L. (1976), *Interim Radiochemical Methodology for Drinking Water*, U.S.E.P.A. Report EPA-600/4-75-008 (Revised), Cincinnati. (Available from N.T.I.S., Springfield, Va.)

Krishnaswami, S., D. Lal, B.L.K. Somayajulu, F.S. Dixon, S.A. Stonecipher, and H. Craig (1972), "Silicon, radium, thorium, and lead in seawater: in-situ extraction by synthetic fibre", *Earth Planet. Sci. Lett.*, 16, 84.

Kuchta, D.R., J. Rundo, and R.B. Holtzman (1976), "Low-level determination of skeletal  $^{228}\text{Ra}$  and  $^{228}\text{Th}$  in the presence of gross amounts of  $^{226}\text{Ra}$  in Biological and Environmental Effects of Low-Level Radiation, *proc. Symp.* Nov. 3-7, 1975, Chicago; vol. II, p. 183, I.A.E.A., Vienna.

Lund, E. (1976), "Report of a working group on radiological examination of water", *Water Res.*, 10, 179.

Mackenzie, A.B., M.S. Baxter, I.G. McKinley, D.S. Swan, and W. Jack (1979), "The determination of  $^{134}\text{Cs}$ ,  $^{137}\text{Cs}$ ,  $^{210}\text{Pb}$ ,  $^{226}\text{Ra}$  and  $^{228}\text{Ra}$  concentrations in nearshore marine sediments and seawater", *J. Radioanal. Chem.*, 48, 29.

McCurdy, D.E., and R.A. Mellor (1979), "An alternative technique for the determination of  $^{226}\text{Ra}$  and  $^{228}\text{Ra}$  in drinking water", presented at 24th ann. meeting of Health Physics Soc., July 8-13, 1979, Philadelphia.

Michel, J., and W.S. Moore (1980), " $^{228}\text{Ra}$  and  $^{226}\text{Ra}$  content of groundwater in fall line aquifers", *Health Physics*, 38, 663.

Moore, W.S. (1969a), "Measurement of  $^{228}\text{Ra}$  and  $^{228}\text{Th}$  in sea water", *J. Geophys. Res.*, 74, 694.

Moore, W.S. (1969b), "Oceanic concentrations of  $^{228}\text{radium}$ ", *Earth Planet. Sci. Lett.*, 6, 437.

Moore, W.S. (1976), "Sampling  $^{228}\text{Ra}$  in the deep ocean", *Deep-Sea Res.*, 23, 647.

Moore, W.S., and D.F. Reid (1973), "Extraction of radium from natural waters using manganese-impregnated acrylic fibers", *J. Geophys. Res.*, 78 (36), 8880.

Percival, D.R., and D.B. Martin (1974), "Sequential determination of radium-226, radium-228, actinium-227, and thorium isotopes in environmental and process waste samples", *Anal. Chem.*, 46, 1742.

Petrow, H.G., and R.J. Allen (1961), "Estimation of the isotopic composition of separated radium samples", *Anal. Chem.*, 33, 1303.



Petrow, H.G., A. Cover, W. Scheissle, and E. Parsons (1964), "Radiochemical determination of radium-228 and thorium-228 in biological and mineral samples", Anal. Chem., 36, 1600.

Sakanoue, M., T. Nomura, T. Imai, and H. Uzuyama (1973), "Radiochemical studies on  $^{228}\text{Ra}$  in sea water and  $^{231}\text{Pa}$  in sea sediments", in Proceedings of Symposium on Hydrogeochemistry and Biogeochemistry, Sept. 7-9, 1970, Tokyo, vol. 1, p. 293.

Sekine, T., Y. Koike, and M. Sakairi (1966), "Studies of actinium (III) in various solutions, (I) Separation and purification of  $^{228}\text{Ac}$  in  $^{228}\text{Ra}$  solutions by solvent extraction method", J. Nucl. Sci. Tech., 4, 308.

Smith, K.A., and E.R. Mercer (1970), "The determination of radium-226 and radium-228 in soils and plants, using radium-225 as a yield tracer", J. Radioanal. Chem., 5, 303.

Tomza, I. (1977), "Determination of low radium concentrations in mineralized waters", in Proceedings of the International Conference on Low-Radioactivity Measurements and Applications, Oct. 6-10, 1975, The High Tatras, Czechoslovakia, p. 387 (in Russian).

Trier, R.M., W.S. Broecker, and H.W. Feely (1972), "Radium-228 profile at the second Geosecs intercalibration station, 1970, in the north Atlantic", Earth Planet. Sci. Lett., 16, 141.

Whittaker, E.L. (1980), Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency, Las Vegas; personal communication.

The following papers were obtained too late to include in Table 1. They do not alter the conclusions of this report because none is suitable as a reference method for radium-228 assays. The radiochemical section of the Herment paper deals with the production of radium-228. Neither of the other two papers has a way to determine the chemical yield of an assay.

Herment, M. (1971), Chemical Separation and High Resolution Nuclear Spectroscopy in the  $^{228}\text{Ra}$   $^{228}\text{Ac}$   $^{228}\text{Th}$  Radioactive Chain, Univ. Grenoble Report FRNC-TH-184 (in French).

Kharbanda, J.L., M.V. Rajan, R.V. Amalraj, K.T. Thomas (1966), "Separation and estimation of radium-228 in thorium plant effluent", in Proc. Nucl. Radiat. Chem. Symp., Jan. 20-22, 1966, Waltair, p. 46.

Sebessy, L., E. Upor, and I. Vados (1967), "Determination of the radium-226/radium-228 ratio in natural waters", in Proc. Conf. Appl. Phys.-Chem. Methods Chem. Anal., 1966, Budapest, Vol. 2, p. 245.

Table 1. Comparison of Major Features of Methods for the Assay of Radium-228 in Water

Reference	Intended Use	Sample Size	Preliminaries	Ra Separation	Purification	Final Form	Yielded By	Counted By
Baratta and Feldman (1961)	Assay of Ac in U mill effluents and natural waters	1 liter	Ac pptd. with La (12 mg) by HF					
Humphrey et al. (1975)	$^{226}\text{Ra}$ and $^{228}\text{Ra}$ in effluent solutions with high ion concentration	250 ml	None	On $\text{Ba}(\text{NO}_3)_2$ in 70% $\text{HNO}_3$ . Sulfate ion interferes	By AG50W-X8 ion exchange column operated at 60°. Eluted with 3 M $\text{HNO}_3$	Solution evap. on stainless steel planchet, planchet flamed	Nothing	Frisch-grid ionization chamber of 4.78 MeV $\alpha$ with PHA
Iyer et al. (1966)	Estimation of $^{226}\text{Ra}$ in monazite and Th samples	2 to 5 g	Digest with $\text{H}_2\text{SO}_4$ in Pt dish and fuse with $\text{Na}_2\text{CO}_3$ and $\text{K}_2\text{CO}_3$ . Dissolve in $\text{HNO}_3$	On 100 mg of Ba pptd. as $\text{BaCO}_3$ . Ba weighed before and after Ra separation				
Johns et al. (1979)	$^{226}\text{Ra}$ and $^{228}\text{Ra}$ in water, soil, air, and biological samples	1500 g water, 1 g soil, up to 500 cm <sup>2</sup> of air filter, biological not specified	Water, none; digest soil in Paar bomb, then fuse; acid dissolution of air filters	Water, air filters: coppt. on $\text{PbSO}_4$ ; soil: coppt. on $\text{BaSO}_4$	Water and Microsorban filters: none; soil and glass-fiber filters: reppt. on $\text{BaSO}_4$	Water and Microsorban filters: OPTA complex in acetic acid; others: chloride solution	Nothing	Rn de-emanated into scintillation chamber after 30 days ingrowth. Counting begun 4.5 h after transfer
Kahlos and Asikainen (1973)	Assay of natural radioactivity in ground water	1 liter	Citric acid and $\text{NH}_4\text{OH}$ added to filtered sample, then Ba and Pb carriers	Mixed sulfates pptd. with $\text{H}_2\text{SO}_4$	Dissolve ppt. in alkaline EDTA solution, reppt. sulfates at pH 4.5 with acetic acid	$\text{Ba}(\text{Ra})\text{SO}_4$ on planchet	Weighing of $\text{Ba}(\text{Ra})\text{SO}_4$ ppt.	$\text{ZnS}(\text{Ag})$ -activated $\alpha$ -particle scintillation counter
Kaufman et al. (1973), Broecker et al. (1973)	$^{228}\text{Ra}$ and $^{228}\text{Th}$ in sea water	600 to 800 l	Acidify with HCl, add Fe and Ba carriers, $^{230}\text{Th}$ ppt. $\text{Fe}(\text{OH})_3$ and $\text{Ba}(\text{Ra})\text{SO}_4$ with $\text{NH}_4\text{OH}$	Hydroxides dissolved in HCl; sulfates transposed to carbonates, dissolved in HCl	None	Rn de-emanated by He gas. Rn frozen out of He in liquid air-cooled trap	Nothing. Moore (1969b) found initial sulfate pptn. to be 60% to 90% efficient	$\alpha$ -scintillation detector
Koide and Rruland (1975)	$^{226}\text{Ra}$ , $^{228}\text{Ra}$ and other natural emitters in sea water and marine sediments	20 l water, 1 to 5 g sediment	Add Pb carrier, $^{228}\text{Ra}$ tracer. Sediment: ignite and leach with HCl	Water: coppt. on $\text{AlPO}_4$ , dissolve in 4 M $\text{HNO}_3$ . Sediment: coppt. on $\text{Pb}(\text{NO}_3)_2$ with 75% $\text{HNO}_3$	Separate Ra and Pb on anion exchange column, alkaline earths on cation exchange column	Electroplated on Pt planchet after at least two weeks wait for unsupported $^{226}\text{Ra}$ to decay	$^{223}\text{Ra}$ tracer. $^{227}\text{Ac}$ "cow" is required	$\alpha$ -spectrometry with semiconductor detector
Krieger (1975), based on Johnson (1971)	$^{226}\text{Ra}$ and $^{228}\text{Ra}$ in drinking water	At least 1 liter	Add citric acid, Pb, Ba, and Y carriers; heat	Add $\text{NH}_4\text{OH}$ , ppt. mixed sulfates with $\text{H}_2\text{SO}_4$ , then add $(\text{NH}_4)_2\text{SO}_4$	Multiple copptn. on $\text{Ba}(\text{NO}_3)_2$ and on $\text{BaSO}_4$	In alkaline EDTA solution, or in $\text{BaSO}_4$ ppt. on stainless steel planchet	$\text{BaSO}_4$ gravimetrically	Rn de-emanation into scintillator cell
Kuchta et al. (1976)	Assay of skeletal $^{226}\text{Ra}$ and $^{228}\text{Th}$ in presence of gross amounts of $^{226}\text{Ra}$	Not specified	Ory-ash bone sample, dissolve ash in $\text{HNO}_3$	None				

R A D I U M - 2 2 B

Special Items	Purification	Final Form	Yielded By	Waiting Period	Counted By	Special Items	Comments
	Liquid-liquid extractions using TTA in benzene; ion exchange columns	La(Ac) oxalate. Iyer et al. (1966) think Y is better than La as carrier	Not mentioned, but could be gravimetrically	None stated, but sample should be two days old before starting assay	G-M tube or proportional counter, with absorber when $^{228}\text{Ac}$ is present	None	Sekine et al. (1967) say TTA equimolar with TBP in $\text{CCl}_4$ is superior to TTA only
Heated ion exchange columns (60°C)	2nd ion exchange column at 60°C. Ac eluted with 6 M $\text{HNO}_3$	Solution evap. on stainless steel planchet	Nothing	24 h for $^{228}\text{Ac}$ ingrowth	Gas-flow proportional counter with 13 mg/cm <sup>2</sup> absorber	Sage as for $^{226}\text{Ra}$	Ba initially present in samples. Na, K, Ca, Mg, and Al each more than 100 mg/l in typical sample
	Ac copptd. on $\text{Fe}(\text{OH})_3$ , impurities scavenged on Pb and Bi sulfides	$\text{Fe}(\text{Ac})(\text{OH})_3$ dissolved in $\text{HNO}_3$ . Known fraction evap. on planchet	Weighings of ppt. containing Ra and Ac, or spectrophotometric assay of Fe	24 h for $^{228}\text{Ac}$ ingrowth	End-window, gas-flow proportional counter	Pt crucible; spectrophotometer (Fe line at 304 nm used)	Method not tried on very low activity samples
Paar bomb; Pt dish for glass-fiber filter and soil samples	Reppt. $8\alpha(\text{Ra})\text{SO}_4$ dissolve, extract Ac into OEHFA, back extract into 1 M $\text{HNO}_3$	Evap. acid solution to dryness on 5-cm diameter planchet	Nothing	About 30 d for $^{222}\text{Rn}$ ingrowth; at least 30 h for $^{228}\text{Ac}$ ingrowth	Low-background proportional counter. Time $T_2$ is ambiguously specified	None besides those for $^{226}\text{Ra}$	Method could be changed to assay $^{228}\text{Ra}$ first. No specifics given for assaying biologicals. Section 11 wrongly states no $^{226}\text{Ra}$ std. are available
None. Method based on that of Goldin (1961)	Dissolve ppt., add Ce carrier, transfer to deposition cell, add Te; Pb, Bi, and Po plate out.	Ppt. Ce with NaOH, dissolve ppt. in $\text{HNO}_3$ , add $8\alpha$ holdback carrier, reppt. Ac on $\text{Ce}(\text{OH})_3$	Nothing, but final ppt. could be Ce oxalate, which is weighable for yield	About 30 d for $^{222}\text{Rn}$ ingrowth	Low-background $\beta$ counter, type unspecified	Constant temperature bath, for the spontaneous electrodepositon step	$^{226}\text{Ra}$ could be counted by de-emanation of $^{222}\text{Rn}$
Liquid air-cooled trap for Rn	Th copptd. $^{230}\text{Th}$ $\text{Fe}(\text{OH})_3$ ; Th spike added, solution stored; Th copptd. on $\text{Fe}(\text{OH})_3$	Th purified on cation and anion exchange columns, extracted into TTA in benzene, evap.	$^{226}\text{Ra}$ assays of sample initially and during $^{228}\text{Th}$ ingrowth plus $^{230}\text{Th}$ tracer	4 to 11 months for $^{228}\text{Th}$ ingrowth	$\alpha$ spectrometry; counting system not specified	None additional	Method is based in part on Moore (1969a). Knauss et al. (1978) found precision of assays better by counting $^{228}\text{Th}$ than by counting $^{226}\text{Ac}$
$^{227}\text{Ac}$ "cow". Ultrasonic agitator	See under $^{226}\text{Ra}$ ; none additional	On same planchet as $^{226}\text{Ra}$	$^{226}\text{Ra}$ counting of $^{223}\text{Ra}$	At least 2 weeks for $^{224}\text{Ra}$ and progeny to decay	$^{228}\text{Ac}$ in proportional counter with Al absorber. Other emitters must be filmed off planchet	None additional	$^{228}\text{Ra}/^{226}\text{Ra}$ activity ratio must be at least 0.1. As check, ingrown $^{228}\text{Th}$ can be counted later. Cochran (1979) completely dissolved sediments.
None	As for $^{226}\text{Ra}$ plus copptn. of ingrown Ac on $\text{Y}(\text{OH})_3$	In Y oxalate ppt.	Weighing of Y oxalate	At least 36 h for $^{228}\text{Ac}$ ingrowth of $^{226}\text{Ra}$	$^{228}\text{Ac}$ in gas-flow proportional counter	None	Chemical yield of Ac is incorrectly calculated - see text
	None except by Rn de-emanation using a flow-through collection chamber	Solution is de-emanated, $^{226}\text{Rn}$ and progeny collected on negatively charged electrode	Nothing	2 counts about 1 year apart for samples without equilibrium between $^{228}\text{Ra}$ and $^{228}\text{Th}$	Electrode placed in holder with ZnS-coated Mylar disc or phototube. $^{210}\text{Pb}$ and progeny counted	Flow-through chamber with collection electrode; holder for electrode on phototube	Data are analyzed by computer. Method designed to have poor sensitivity for $^{226}\text{Ra}$

Reference	Intended Use	Sample Size	Preliminaries	Ra Separation	Purification	Final Form	Yielded By	Counted By
Mackenzie et al. (1979)	Assay of $^{226}\text{Ra}$ and other radionuclides in sea water and marine sediments	Water: 10 to 20 l for $^{226}\text{Ra}$ 1000 l for $^{228}\text{Ra}$ . Sediment: 5 to 10 g	Water: filter, acidify. Sediment: complete dissolution in Teflon with mixture of acids	$^{226}\text{Ra}$ : none. $^{228}\text{Ra}$ : absorb on $\text{MnO}_2$ , desorb with $\text{HCl}$ , coppt. on $\text{BaSO}_4$	None	$^{222}\text{Rn}$ gas	Nothing, but authors say assay is quantitative	$\alpha$ -scintillation in modified Lucas cell
McCurdy and Mellor (1979)	$^{226}\text{Ra}$ and $^{228}\text{Ra}$ in drinking water	2 l	Add citric acid, adjust pH to 9.5, add Ba carrier (known amount)	On $\text{BaSO}_4$ pptd. with $\text{H}_2\text{SO}_4$	Dissolve ppt. in alkaline EDTA solution, reppt. $\text{BaSO}_4$ with acetic acid	$\text{BaSO}_4$ ppt. mixed with ZnS powder. ZnS/ $\text{BaSO}_4$ ratio is approximately 2.4	Weighing of $\text{BaSO}_4$ ppt.	$\alpha$ - $\gamma$ coincidence counting of $^{226}\text{Ra}$
Michel and Moore (1980)	Assays of $^{226}\text{Ra}$ and $^{228}\text{Ra}$ in ground waters	$^{226}\text{Ra}$ : 0.8 l; $^{228}\text{Ra}$ : 10 to 20 l	None (waters assayed were clear)	$^{226}\text{Ra}$ : none. $^{228}\text{Ra}$ : absorb on $\text{MnO}_2$ -impregnated acrylic fibers, desorb with $\text{HCl}$ , ppt. on $\text{BaSO}_4$	None	$^{222}\text{Rn}$ gas	Nothing, but each sample run at least twice	$\alpha$ -scintillation chamber
Percival and Martin (1974)	$^{226}\text{Ra}$ and $^{228}\text{Ra}$ in soils, water, ores, and mill tailings and effluents	5 g of solids, 0.1 to 1 liter of liquid	Liquids: acidify, wait overnight, coppt. on $\text{PbSO}_4$ , do sulfate fusion	Add acetic acid, coppt. Ra with $\text{BaCl}_2$ on $\text{BaSO}_4$ . Dissolve ppt. in DTPA solution	None	$^{222}\text{Rn}$ gas	Nothing	Pulse-ionization chamber or $\alpha$ -scintillation cell
Petrow et al. (1964)	Assay of $^{226}\text{Ra}$ and $^{228}\text{Th}$ in biological and mineral samples	Up to 50 g of bone ash; up to 20 g of food or plant ash; 5 g of minerals	Minerals: fuse with $\text{Na}_2\text{CO}_3$ , digest in $\text{NaOH}$ . All types: dissolve in acid	Liquid-liquid extractions with Aliquat 336 and DEHPA to remove Th. Coppt. Ra on $\text{PbSO}_4$				
Sakanoue et al. (1973)	$^{228}\text{Ra}$ in sea water and $^{226}\text{Ra}$ in sea sediments	80 l	$\text{BaCl}_2$ and $\text{FeCl}_3$ added, then $\text{NH}_3$ . $\text{Fe}(\text{OH})_3$ and $\text{BaSO}_4$ ppt.	$\text{Fe}(\text{OH})_3$ ppt. dissolved with $\text{HCl}$ . $\text{Ba}(\text{Ra})\text{SO}_4$ converted to carbonates by fusion, dissolved in $\text{HCl}$				$^{222}\text{Rn}$ de-emanation (no specifics given)
Smith and Mercer (1970)	Assay of $^{226}\text{Ra}$ and $^{228}\text{Ra}$ in soils and plants	Up to 10 g of plant ash and soil	Repeated evap. with $\text{HClO}_4$ and HF, dissolve residue in $\text{HCl}$	Coppt. Ra on Ba and Pb sulfates. Ppt. dissolved in alkaline EDTA, sulfates repptd. with acetic acid	Cation exchange separation of Ra and Ba; Ra coppt. on $\text{Pb}(\text{NO}_3)_2$ , separated by anion exchange at 60	Electroplated on stainless steel planchet	$^{133}\text{Ba}$ for dissection only, $^{226}\text{Ra}$ for entire assay, from $^{228}\text{Th}$ "cow"	$\alpha$ -spectrometry with Frisch-grid pulse-ionization chamber
Tomza (1977)	Assay of low Ra concentrations in mineralized waters	10 l	Add citric acid and $\text{NH}_4\text{OH}$ , then Pb and Ba carriers	Mixed sulfates pptd. with $\text{H}_2\text{SO}_4$	Ppt. dissolved in alkaline EDTA then repptd. by acetic acid at pH 4.5	$\text{Ba}(\text{Ra})\text{SO}_4$ ppt. dispersed in toluene containing PPD, POPOP, and colloidal silica	Nothing	Liquid-scintillation, two counts several weeks apart

## ABBREVIATIONS:

$\alpha$  =  $\alpha$  particle  
 $\beta$  =  $\beta$  particle  
 coppt. = coprecipitate  
 DEHPA = bis(2-ethylhexyl)phosphoric acid

DTPA = sodium diethylenetriaminepenta acetate  
 EDTA = sodium ethylenediaminetetraacetate  
 evap. = evaporate, evaporated  
 G-M = Geiger-Müller

PHA = pulse height analyzer  
 POPOP = 1,4-di-(2-(S-phenyloxazolyl))-benzene  
 PPD = 2,5-diphenyloxazole  
 ppt. = precipitate (as verb and as noun)



RADIUM - 228

Special Items	Purification	Final Form	Yielded By	Waiting Period	Counted By	Special Items	Comments
25-liter glass vessel for equilibration of Rn in water samples, liquid N <sub>2</sub> -cooled trap for <sup>222</sup> Rn	Sr removal step; extractions of Ac by TTA in benzene; store 5 weeks; more extractions of Ac	Evap. organic phases on heated stainless steel planchet	After <sup>228</sup> Ac assays, sample assayed for <sup>226</sup> Ra. Extraction of Ac is not yielded	12 d for <sup>222</sup> Rn ingrowth, at least 5 weeks for decay of <sup>228</sup> Th progeny	Tracerlab Omniguard (gas-flow G-M counter with anticoincidence)	MnO <sub>2</sub> -impregnated acrylic fibers, Pt crucible	Method does not discuss assay of <sup>228</sup> Ra in sediments
4 timing SCA, 2 coincidence analyzers, special detector assembly, PHA	None additional. See under <sup>226</sup> Ra	Same as <sup>226</sup> Ra	Same as <sup>226</sup> Ra	<sup>228</sup> Ac ingrowth time not specified, assumed to be 1 to 2 days	$\beta$ - $\gamma$ coincidences counting of <sup>228</sup> Ac	Same as for <sup>226</sup> Ra	Considerable instrumentation is required, but amount of radiochemistry is reduced
Apparently none	Carbonate fusion, dissolve mixed ppt. in HCl, coppt. Th on Fe. Store, add <sup>230</sup> Th, coppt. Th on Fe	Purify Th by ion exchange, mount on planchet for thin source $\alpha$ counting	$\alpha$ spectrometry of Th, <sup>228</sup> Ra assay of concentrated sample. Separate <sup>226</sup> Ra assay also needed	4 to 10 d for <sup>222</sup> Rn ingrowth, 2 to 4 months for <sup>228</sup> Th ingrowth	$\alpha$ spectrometry of <sup>228</sup> Th and <sup>230</sup> Th; counting system not specified	MnO <sub>2</sub> -impregnated acrylic fibers. See Moore (1976) for preparation	Ra extraction by fibers based on Krishnaswami et al. (1972) and on Moore and Reid (1973)
Pt dish	Remove Ba as sulfate, extract Ac from supernate into 15% DEHPA, strip into HNO <sub>3</sub>	Add Ce, coppt. Ac on Ce exalate	Nothing	At least 20 h for <sup>228</sup> Ac ingrowth	Gas-flow proportional counter	None additional	
	Metathesize ppt. to carbonates, dissolve, coppt. Ra on Pb(NO <sub>3</sub> ) <sub>2</sub> ; extract Ac with DEHPA, Aliquat	Evap. final acid solution on 5-cm diameter stainless steel planchet	Nothing	At least 36 h for <sup>228</sup> Ac ingrowth	$\beta$ from decay of <sup>228</sup> Ac. Instrument unspecified	Pt crucible	This method is extension of similar method by Petrow and Allen (1961) for U mill effluents which also is unyielded
	Extract Ac into DEHPA, back extract into HNO <sub>3</sub> , load on Dorex 50 ion exchange column, elute with 6 M HNO <sub>3</sub>	Evap. on stainless steel plate	<sup>226</sup> Ra assay on initial sample and on Ba(Ra)Cl <sub>2</sub> solution just before Ac extraction. Extraction is not yielded	Unspecified. Assume 27 d for each of 2 <sup>222</sup> Rn ingrowths	$\beta$ counting of <sup>228</sup> Ac in guarded, gas-flow proportional counter, or in Fujitsu "pico beta" $\beta$ spectrometer	None	
Heated ion exchange column; <sup>228</sup> Th "cow"; <sup>133</sup> Ba tracer	Coppt. Ac on Fe, solution stored, Ac reppt. on Fe, Ac separated on anion exchange column from Fe	Solution evap. on stainless steel planchet	$\beta$ counting of <sup>225</sup> Ac and progeny. <sup>133</sup> Ba not needed if method used with water sample	7 to 10 d for growth of <sup>225</sup> Ac	$\beta$ counting of <sup>225</sup> Ac and <sup>228</sup> Ac in gas-flow proportional counter with 13 mg/cm <sup>2</sup> absorber	None additional	Alternate <sup>228</sup> Ra method: $\alpha$ spectrometry after several months wait of <sup>210</sup> Po and <sup>225</sup> Ra on the Ra planchet, without further chemistry
None	Simultaneous with <sup>226</sup> Ra	Same as for <sup>226</sup> Ra	Nothing	Equilibrium between <sup>228</sup> Ra and <sup>228</sup> Th assumed. If not so, must reassay several months later	Liquid-scintillation counting of <sup>228</sup> Ra and progeny $\beta$ pulses of <sup>228</sup> Ra discriminated against	None	Use of moderately complex equations of ingrowth and decay is required

reppt. = reprecipitate  
 SCA = single channel analyzer  
 std. = standard  
 TBP = tributylphosphate  
 TTA = 2-theonyltrifluoroacetone

U.S. DEPT. OF COMM. <b>BIBLIOGRAPHIC DATA SHEET</b> <i>(See instructions)</i>	1. PUBLICATION OR REPORT NO. NBS TN 1137	2. Performing Organ. Report No.	3. Publication Date February 1981
4. TITLE AND SUBTITLE  Evaluation of Methods for the Assay of <sup>228</sup> Ra in Water			
5. AUTHOR(S) J.R. Noyce			
6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)  NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			7. Contract/Grant No.  8. Type of Report & Period Covered Final
9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)  Quality Assurance Division Environmental Monitoring Systems Laboratory U.S. Environmental Protection Agency, P.O. Box 15027 Las Vegas, NV 89114			
10. SUPPLEMENTARY NOTES  <input type="checkbox"/> Document describes a computer program; SF-185, FIPS Software Summary, is attached.			
11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)  The technical literature from 1967 to May 1980 was searched for methods for assaying radium-228 in water. These methods were evaluated for their suitability as potential EPA reference methods for drinking water assays. We suggest the present EPA reference method (Krieger, 1976) be retained but improved, and a second method (McCurdy and Mellor, 1979), which employs β-γ coincidence counting, be added. Included in this report is a table that lists the principal features of 17 methods for radium-228 assays.			
12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons) Analysis; assay; evaluation; radioactivity; radiochemistry; radium-228; reference method; water.			
13. AVAILABILITY  <input checked="" type="checkbox"/> Unlimited <input type="checkbox"/> For Official Distribution. Do Not Release to NTIS <input checked="" type="checkbox"/> Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. <input type="checkbox"/> Order From National Technical Information Service (NTIS), Springfield, VA. 22161			14. NO. OF PRINTED PAGES 18  15. Price \$1.50

There's  
a new  
look  
to...

# DIMENSIONS

... the monthly magazine of the National Bureau of Standards. Still featured are special articles of general interest on current topics such as consumer product safety and building technology. In addition, new sections are designed to . . . PROVIDE SCIENTISTS with illustrated discussions of recent technical developments and work in progress . . . INFORM INDUSTRIAL MANAGERS of technology transfer activities in Federal and private labs. . . DESCRIBE TO MANUFACTURERS advances in the field of voluntary and mandatory standards. The new DIMENSIONS/NBS also carries complete listings of upcoming conferences to be held at NBS and reports on all the latest NBS publications, with information on how to order. Finally, each issue carries a page of News Briefs, aimed at keeping scientist and consumer alike up to date on major developments at the Nation's physical sciences and measurement laboratory.

(please detach here)

## SUBSCRIPTION ORDER FORM

Enter my Subscription To DIMENSIONS/NBS at \$11.00. Add \$2.75 for foreign mailing. No additional postage is required for mailing within the United States or its possessions. Domestic remittances should be made either by postal money order, express money order, or check. Foreign remittances should be made either by international money order, draft on an American bank, or by UNESCO coupons.

Send Subscription to:

NAME-FIRST, LAST

COMPANY NAME OR ADDITIONAL ADDRESS LINE

STREET ADDRESS

CITY

STATE

ZIP CODE

PLEASE PRINT

☐ Remittance Enclosed  
(Make checks payable  
to Superintendent of  
Documents)

☐ Charge to my Deposit  
Account No.

**MAIL ORDER FORM TO:**  
Superintendent of Documents  
Government Printing Office  
Washington, D.C. 20402





## NBS TECHNICAL PUBLICATIONS

### PERIODICALS

**JOURNAL OF RESEARCH**—The Journal of Research of the National Bureau of Standards reports NBS research and development in those disciplines of the physical and engineering sciences in which the Bureau is active. These include physics, chemistry, engineering, mathematics, and computer sciences. Papers cover a broad range of subjects, with major emphasis on measurement methodology and the basic technology underlying standardization. Also included from time to time are survey articles on topics closely related to the Bureau's technical and scientific programs. As a special service to subscribers each issue contains complete citations to all recent Bureau publications in both NBS and non-NBS media. Issued six times a year. Annual subscription: domestic \$13; foreign \$16.25. Single copy, \$3 domestic; \$3.75 foreign.

**NOTE:** The Journal was formerly published in two sections: Section A "Physics and Chemistry" and Section B "Mathematical Sciences."

**DIMENSIONS/NBS**—This monthly magazine is published to inform scientists, engineers, business and industry leaders, teachers, students, and consumers of the latest advances in science and technology, with primary emphasis on work at NBS. The magazine highlights and reviews such issues as energy research, fire protection, building technology, metric conversion, pollution abatement, health and safety, and consumer product performance. In addition, it reports the results of Bureau programs in measurement standards and techniques, properties of matter and materials, engineering standards and services, instrumentation, and automatic data processing. Annual subscription: domestic \$11; foreign \$13.75.

### NONPERIODICALS

**Monographs**—Major contributions to the technical literature on various subjects related to the Bureau's scientific and technical activities.

**Handbooks**—Recommended codes of engineering and industrial practice (including safety codes) developed in cooperation with interested industries, professional organizations, and regulatory bodies.

**Special Publications**—Include proceedings of conferences sponsored by NBS, NBS annual reports, and other special publications appropriate to this grouping such as wall charts, pocket cards, and bibliographies.

**Applied Mathematics Series**—Mathematical tables, manuals, and studies of special interest to physicists, engineers, chemists, biologists, mathematicians, computer programmers, and others engaged in scientific and technical work.

**National Standard Reference Data Series**—Provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated. Developed under a worldwide program coordinated by NBS under the authority of the National Standard Data Act (Public Law 90-396).

**NOTE:** The principal publication outlet for the foregoing data is the Journal of Physical and Chemical Reference Data (JPCRD) published quarterly for NBS by the American Chemical Society (ACS) and the American Institute of Physics (AIP). Subscriptions, reprints, and supplements available from ACS, 1155 Sixteenth St., NW, Washington, DC 20056.

**Building Science Series**—Disseminates technical information developed at the Bureau on building materials, components, systems, and whole structures. The series presents research results, test methods, and performance criteria related to the structural and environmental functions and the durability and safety characteristics of building elements and systems.

**Technical Notes**—Studies or reports which are complete in themselves but restrictive in their treatment of a subject. Analogous to monographs but not so comprehensive in scope or definitive in treatment of the subject area. Often serve as a vehicle for final reports of work performed at NBS under the sponsorship of other government agencies.

**Voluntary Product Standards**—Developed under procedures published by the Department of Commerce in Part 10, Title 15, of the Code of Federal Regulations. The standards establish nationally recognized requirements for products, and provide all concerned interests with a basis for common understanding of the characteristics of the products. NBS administers this program as a supplement to the activities of the private sector standardizing organizations.

**Consumer Information Series**—Practical information, based on NBS research and experience, covering areas of interest to the consumer. Easily understandable language and illustrations provide useful background knowledge for shopping in today's technological marketplace.

*Order the above NBS publications from: Superintendent of Documents, Government Printing Office, Washington, DC 20402.*

*Order the following NBS publications—FIPS and NBSIR's—from the National Technical Information Services, Springfield, VA 22161.*

**Federal Information Processing Standards Publications (FIPS PUB)**—Publications in this series collectively constitute the Federal Information Processing Standards Register. The Register serves as the official source of information in the Federal Government regarding standards issued by NBS pursuant to the Federal Property and Administrative Services Act of 1949 as amended, Public Law 89-306 (79 Stat. 1127), and as implemented by Executive Order 11717 (38 FR 12315, dated May 11, 1973) and Part 6 of Title 15 CFR (Code of Federal Regulations).

**NBS Interagency Reports (NBSIR)**—A special series of interim or final reports on work performed by NBS for outside sponsors (both government and non-government). In general, initial distribution is handled by the sponsor; public distribution is by the National Technical Information Services, Springfield, VA 22161, in paper copy or microfiche form.



**U.S. DEPARTMENT OF COMMERCE**  
**National Bureau of Standards**  
Washington, D.C. 20234

OFFICIAL BUSINESS

Penalty for Private Use, \$300

POSTAGE AND FEES PAID  
U.S. DEPARTMENT OF COMMERCE  
COM-215



SPECIAL FOURTH-CLASS RATE  
BOOK

---